

# Tsunami

by

Harry Yeh

Oregon State University

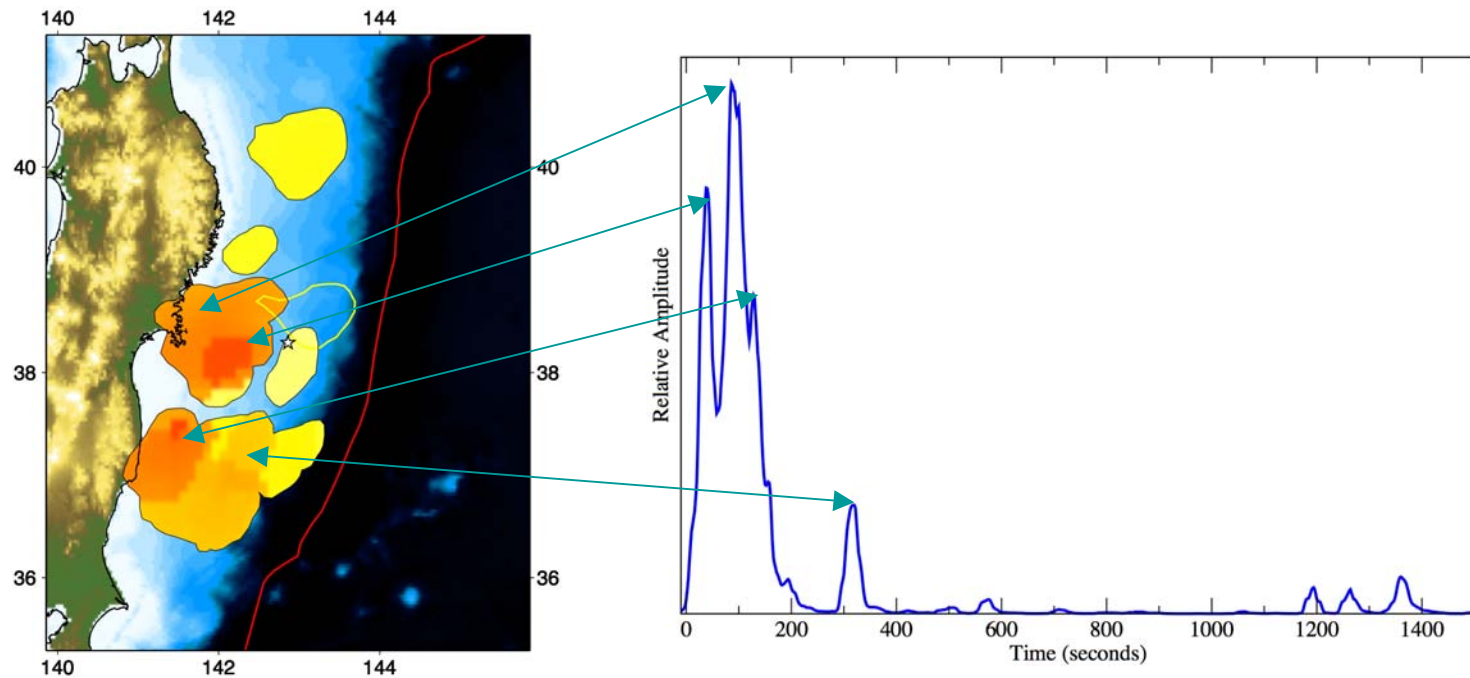


PEER

Eastern Japan Earthquake Disaster Briefing at PEER: April 28, 2011

# Seismic Characteristics

## Rupture Model (Harvard Seismology)

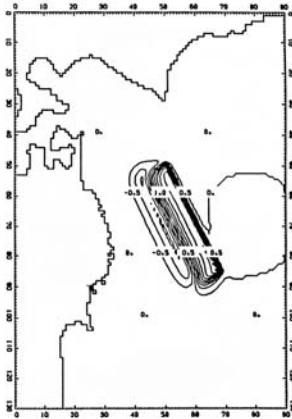


The fault rupture process was **complex**, and the extent of the rupture was approximately 480 km by 170 km.

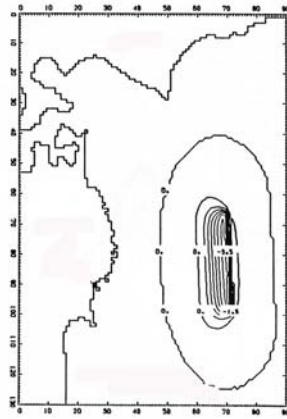
(The 2004 Great Indian Ocean Tsunami: 1300 km by 160 km.)

# Historical Tsunamis in Sanriku Coasts

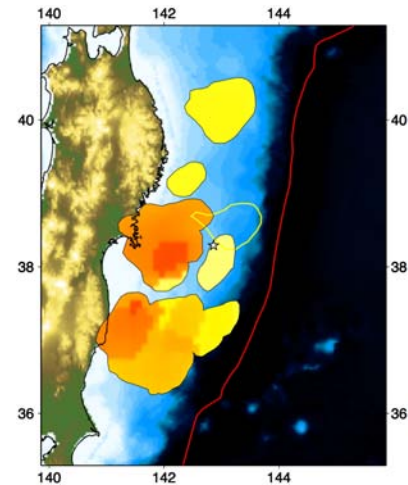
- The 869 Jougan Sanriku Tsunami M8.3 ~ 8.6.
- The 1611 Keichou Sanriku Tsunami M 8.1
  - Maximum tsunami runup height 15 ~ 20 m.
- The 1896 Meiji Sanriku Tsunami M 7.2 (Mw 8.2 ~ 8.5)
  - Maximum tsunami runup height 38.2 m
- The 1933 Showa Sanriku Tsunami (Mw 8.4)
  - Maximum tsunami runup height 28.7 m
- The 2011 Tohoku Tsunami (Mw 9.0)
  - Maximum tsunami runup height 38 m



The 1896 Meiji Tsunami



The 1933 Showa Tsunami

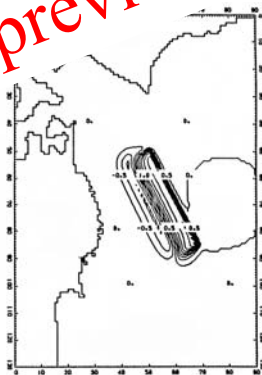


The 2011 Tohoku Tsunami

# Historical Tsunamis in Sanriku Coasts

- The 869 Jogan Sanriku Tsunami  $M 8.3 \sim 8.6$ .
- The 1611 Keichou Sanriku Tsunami  $M 8.1$ 
  - Maximum tsunami runup height 15 ~ 20 m.
- The 1896 Meiji Sanriku Tsunami  $M 8.4$ 
  - Maximum tsunami runup height 24 m
- The 1933 Showa Sanriku Tsunami ( $M 8.4$ )
  - Maximum tsunami runup height 25 m
- The 2011 Tohoku Tsunami ( $M_w 9.0$ )
  - Maximum tsunami runup height 38 m

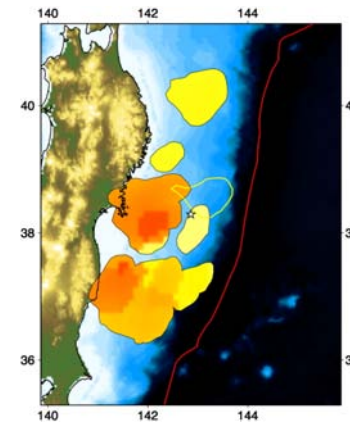
*The fault rupture area is much greater than the previous cases.*



The 1896 Meiji Tsunami



The 1933 Showa Tsunami

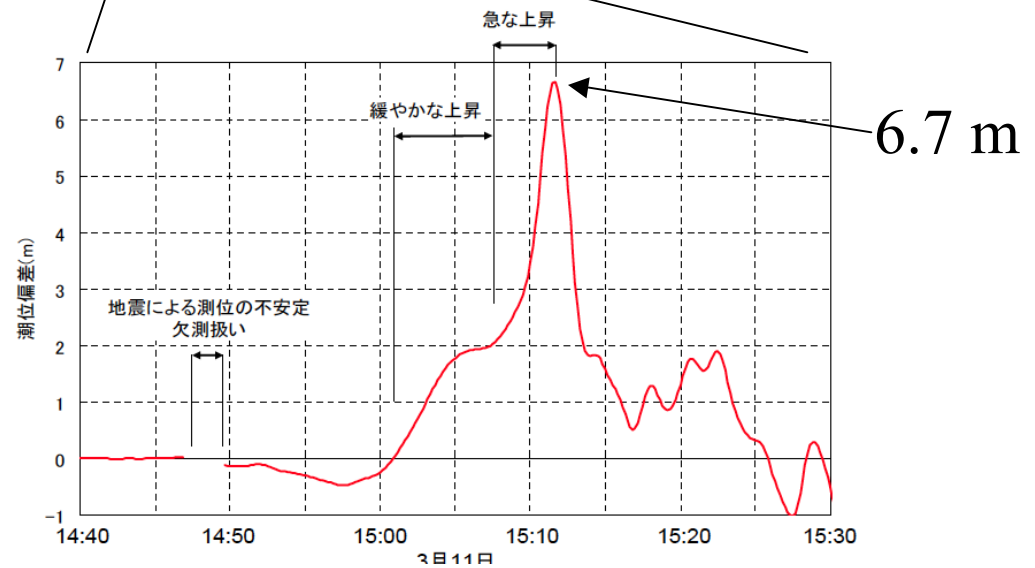
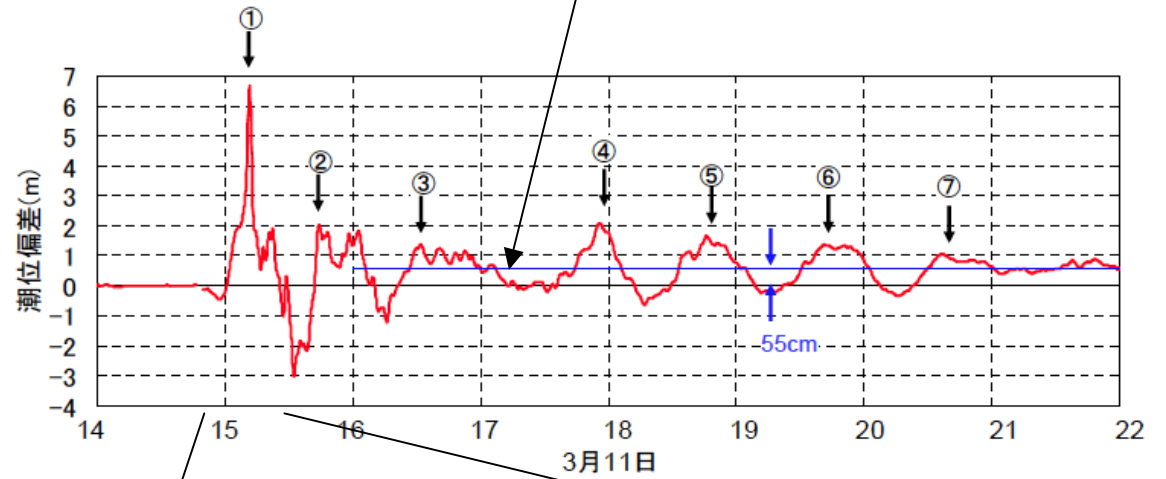
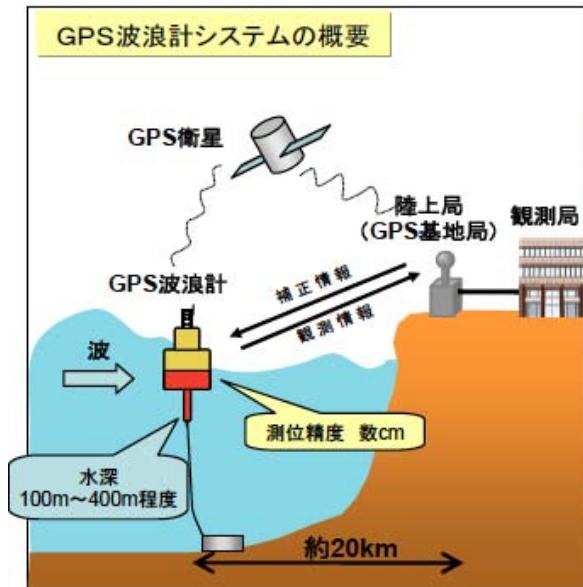


The 2011 Tohoku Tsunami

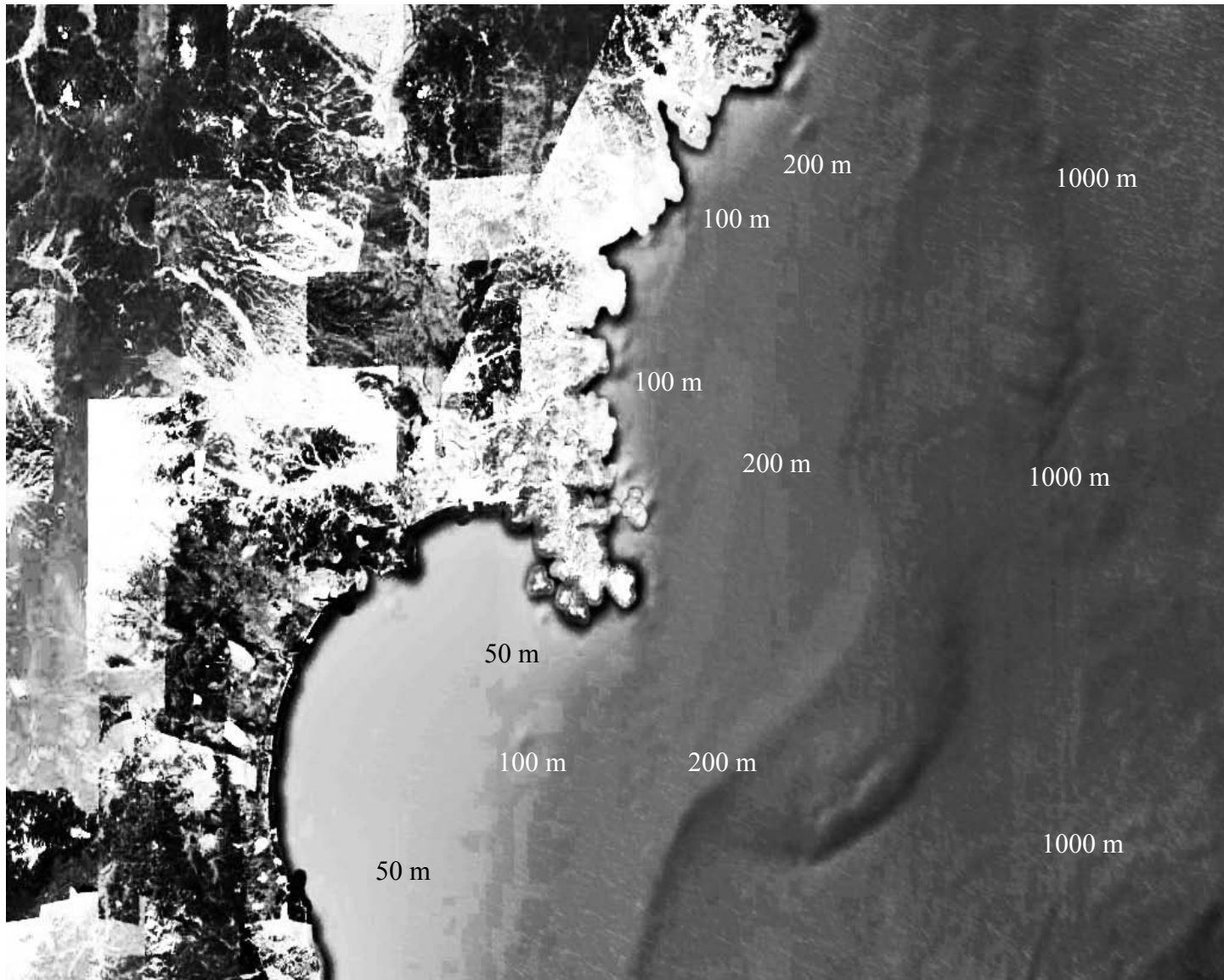
# GPS Wave Gage: 20 km off Kamaishi

Water depth 204 m

55 cm land subsidence



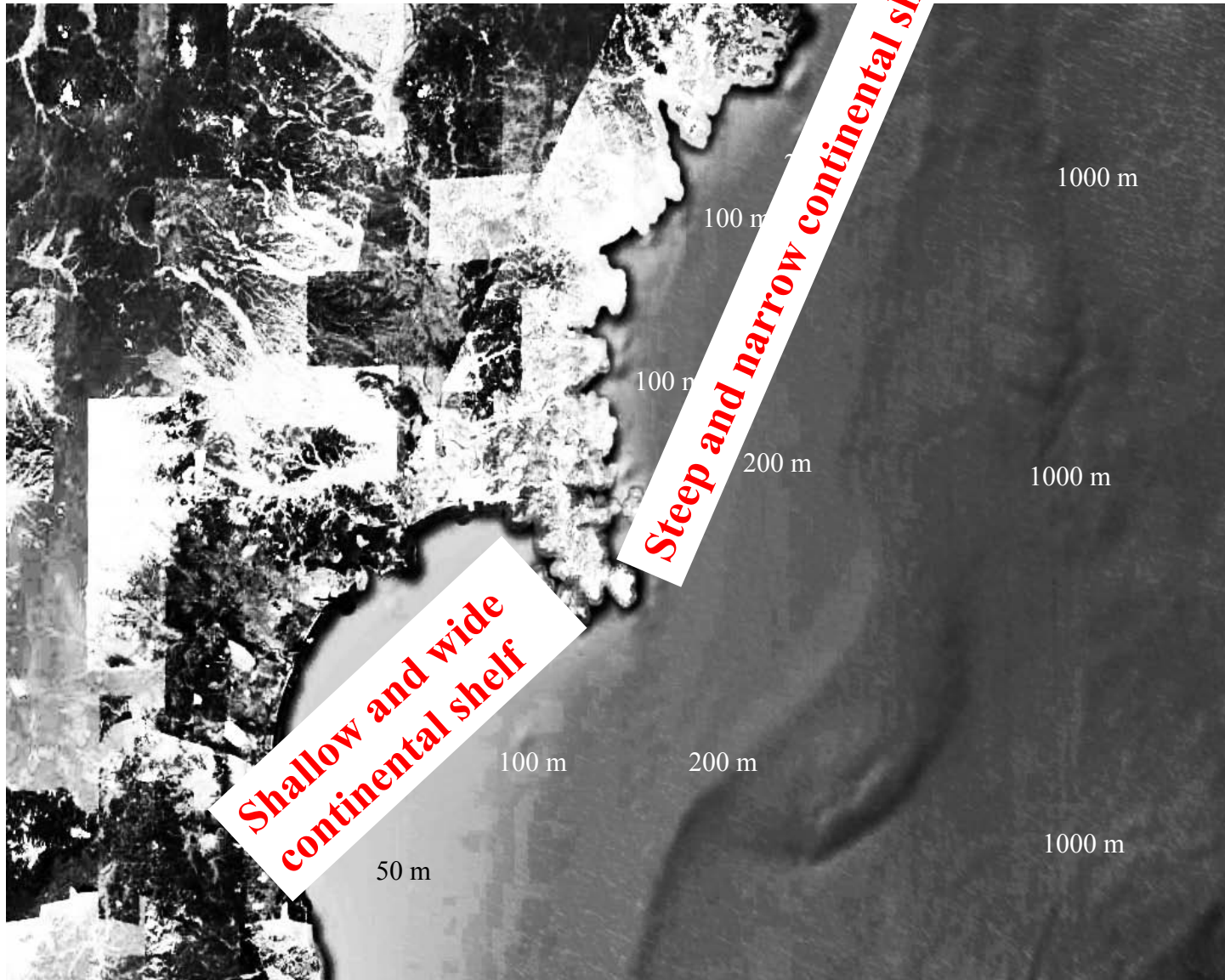
# Bathymetry



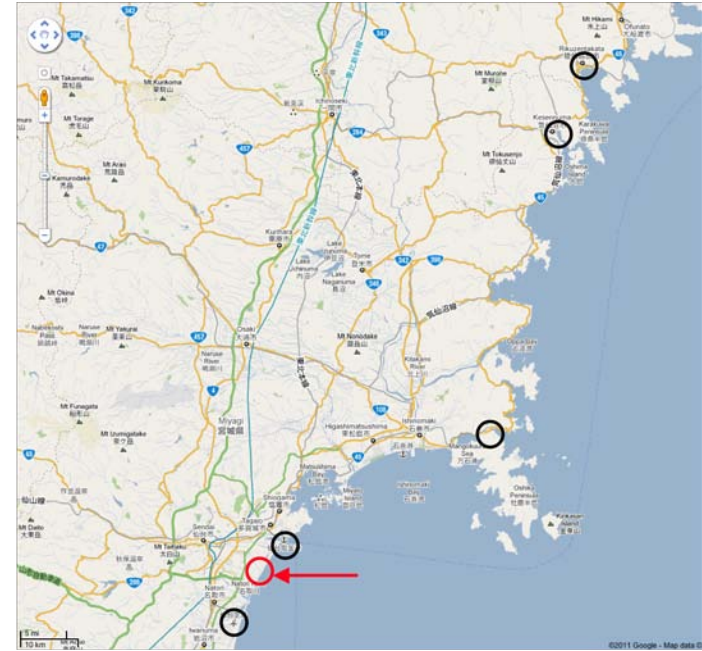
20 km



# Bathymetry



# Arahama



(38°13'14.0"N 140°58'50.5"E)



# Arahama



(38°13'14.0"N 140°58'50.5"E)

# Arahama

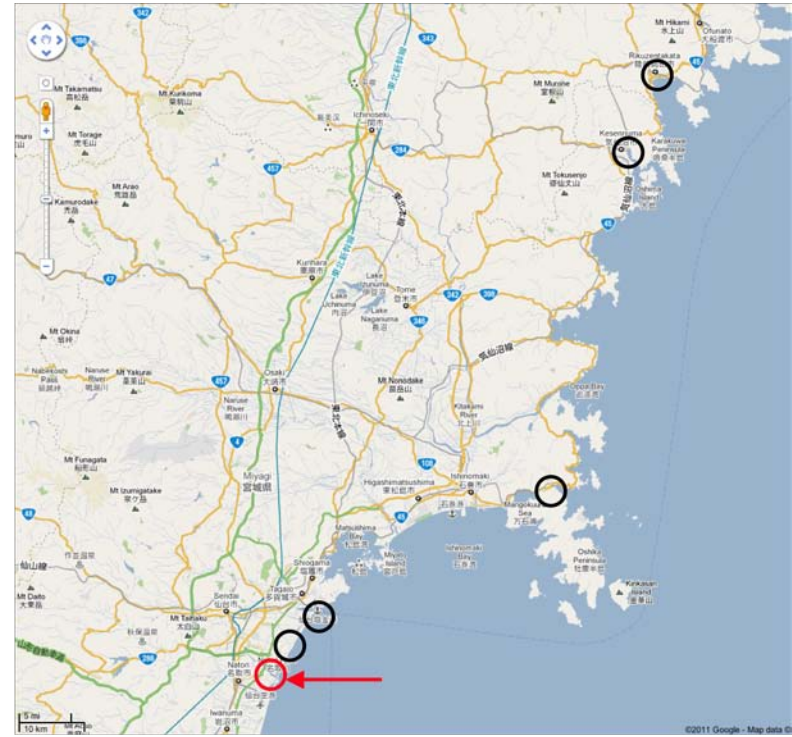


(38°13'14.0"N 140°58'50.5"E)



# Yuriage

A large bus



(38°10'17.0"N 140°57'13.0"E)

# Yuriage



Large scour hole  
7.5m x 15.0m x 1.2m deep

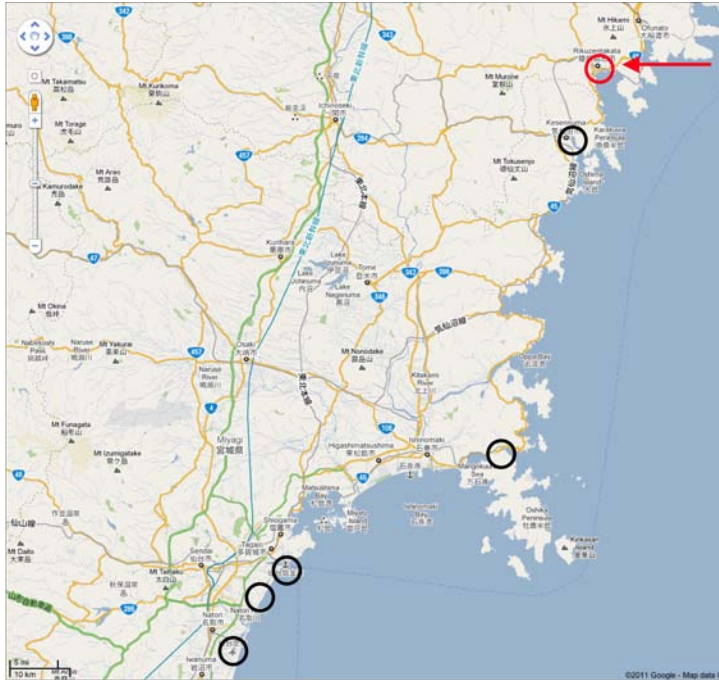
Tsunami induced  
momentary liquefaction?

(38°10'14.6"N 140°57'4.5"E)





# Rikuzen Takada



(39°02'2.0"N 141°36'25.6"E)



# Rikuzen Takada

Strong currents along Kesen River, scouring the railroad bank. Approximately **4 km** upstream from the river mouth.

Max. Runup = 18.5 m



(39°02'2.0"N 141°36'25.6"E)





# Rikuzen Takada before the Tsunami

Tsunami forest and seawall along the shore before the tsunami attack



(39°0'33.6"N 141°38'18"E)

# Rikuzen Takada

Scenes after March 11 tsunami  
-- no forest, no seawall, remain.



Scenes after March 11 tsunami  
-- **84 cm subsidence.**

(39°0'33.9"N 141°38'31.9"E)



# Rikuzen Takada



Front Unit

Front and back windows of every unit were broken away except the top floor.

Inundation elevation near the shore was about 14 ~ 15 m.

(39°0'35.4"N 141°38'38.5"E)

Flooded 90cm above the floor on the top floor

# Rikuzen Takada



1st Unit



2nd Unit

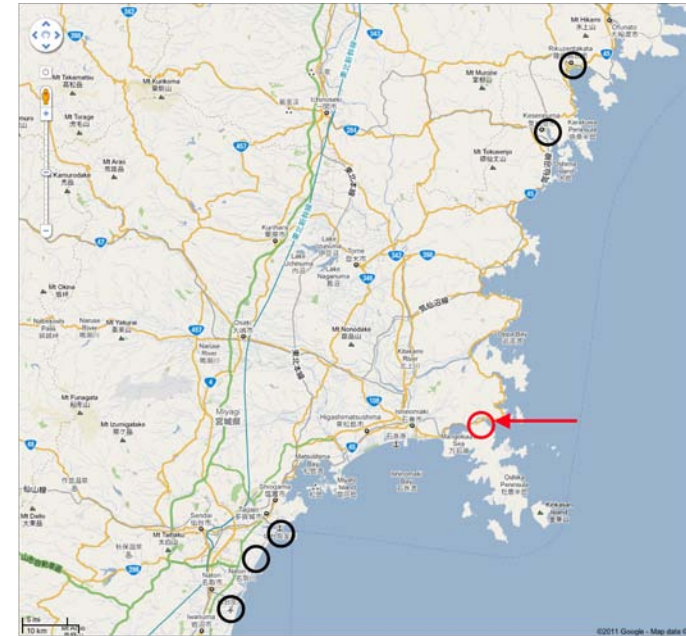
(39°0'35.4"N 141°38'38.5"E)

Flooded 90cm above the floor on the top floor



# Onagawa

17.6 m Runup      120 cm land subsidence.



Tsunami inundation was higher than the top of the concrete cliff.

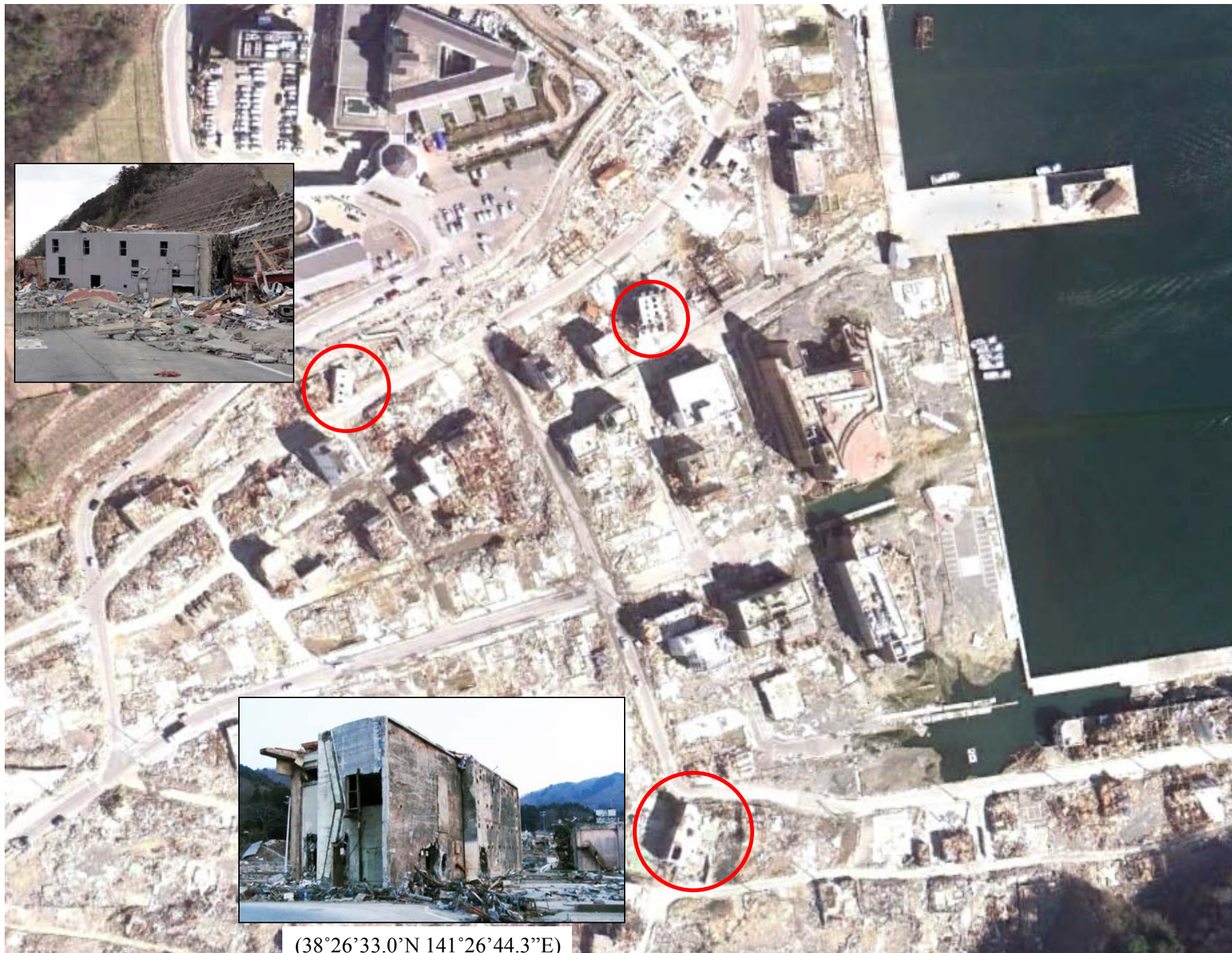


(38°26'33.0"N 141°26'44.3"E)









(38°26'33.0"N 141°26'44.3"E)



# Onagawa



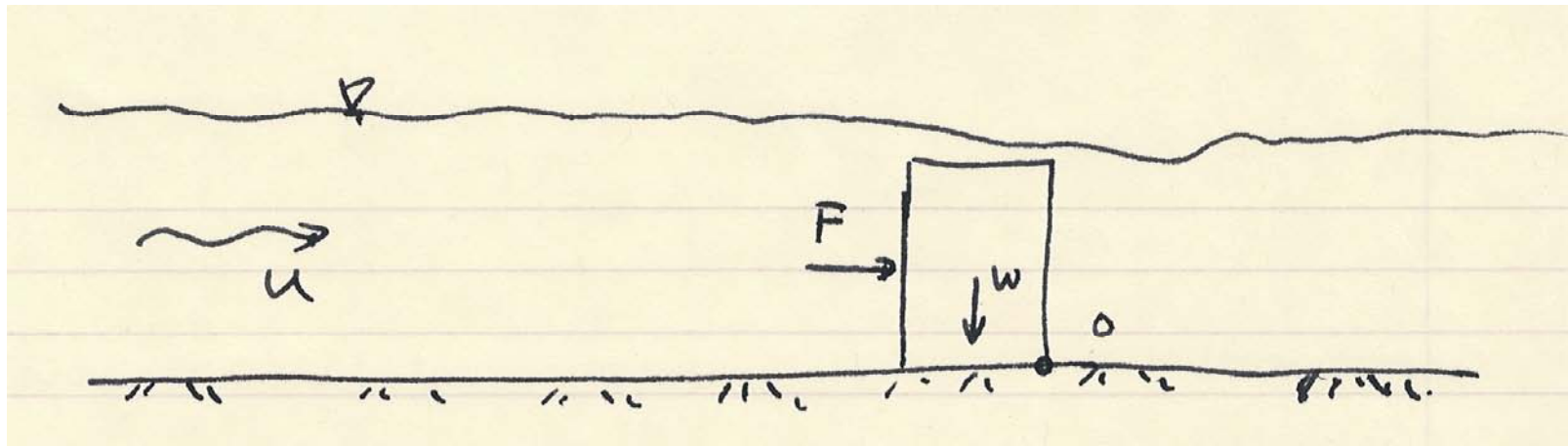
The effective net weight of the building under total submergence is approximately 1,600 KN (estimated by Greg Deierlein).

The fluid force can be estimated by

$$F = \frac{1}{2} C_d \rho A u^2$$

where  $C_d \approx 2$  for a square column.

Take the moment balance at “0” finds the flow speed:  $u \approx 2.5$  m/sec



(38°26'33.0"N 141°26'44.3"E)

# Onagawa



Moment failure of the RC Building -- This is a new finding!

This building can be toppled by rotation when the flow velocity exceeds 2.5 m/sec: this likely happened.

(38°26'33.0"N 141°26'44.3"E)





# Onagawa





# Onagawa



Success story?

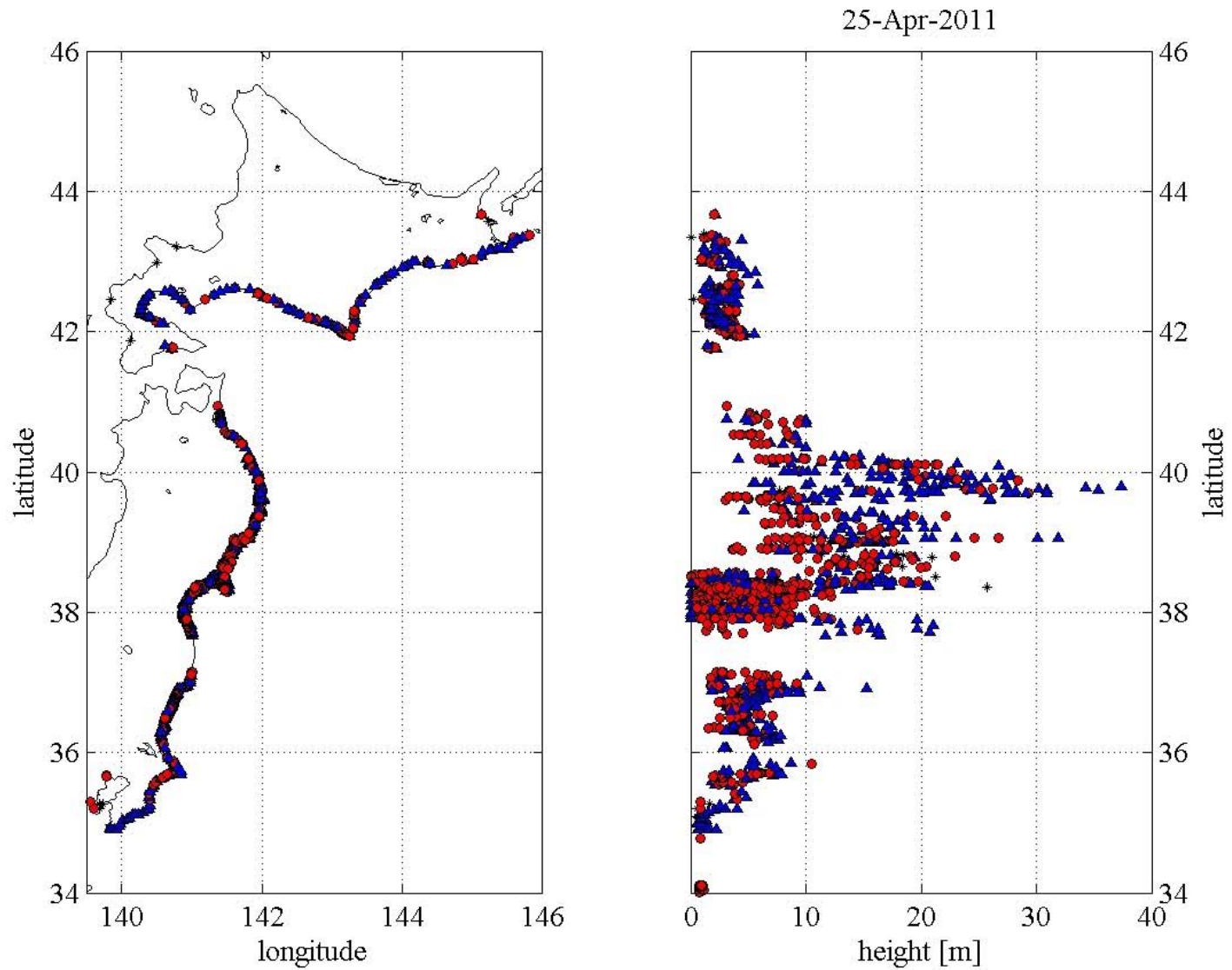
Onagawa NPP



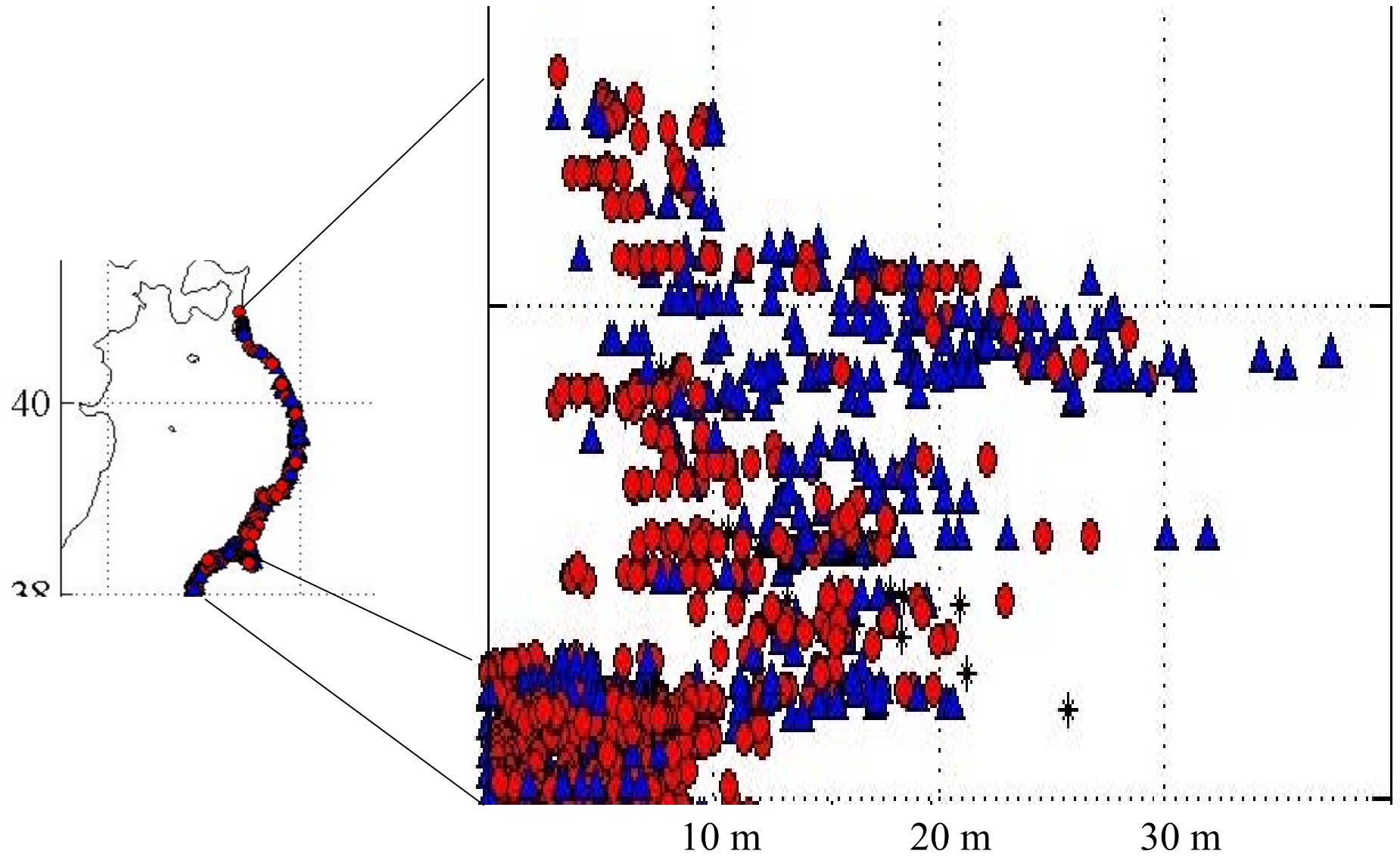
# Consideration on Tsunami Runups



# Tsunami Runup Heights and Inundation Heights

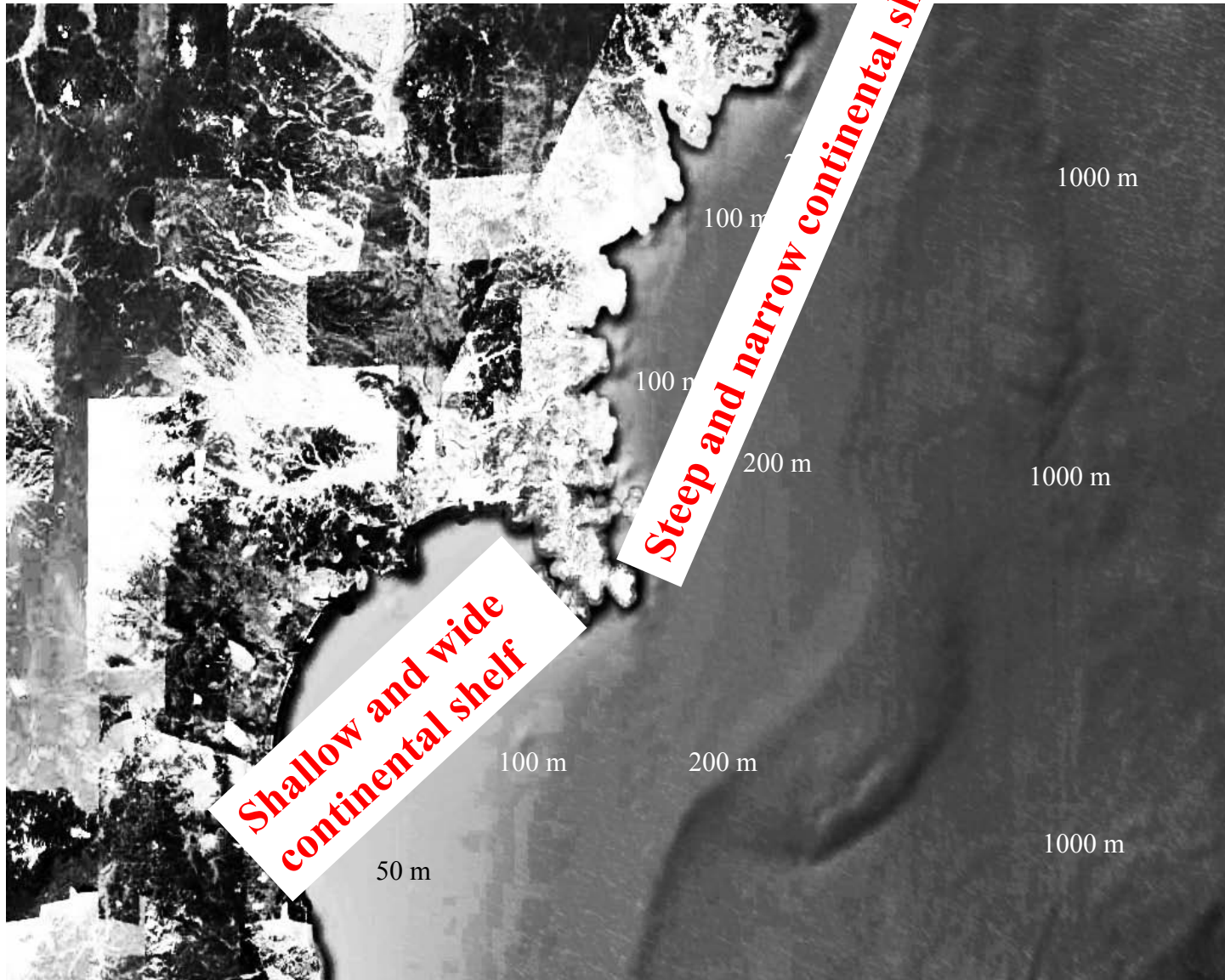


# Tsunami Runup Heights and Inundation Heights

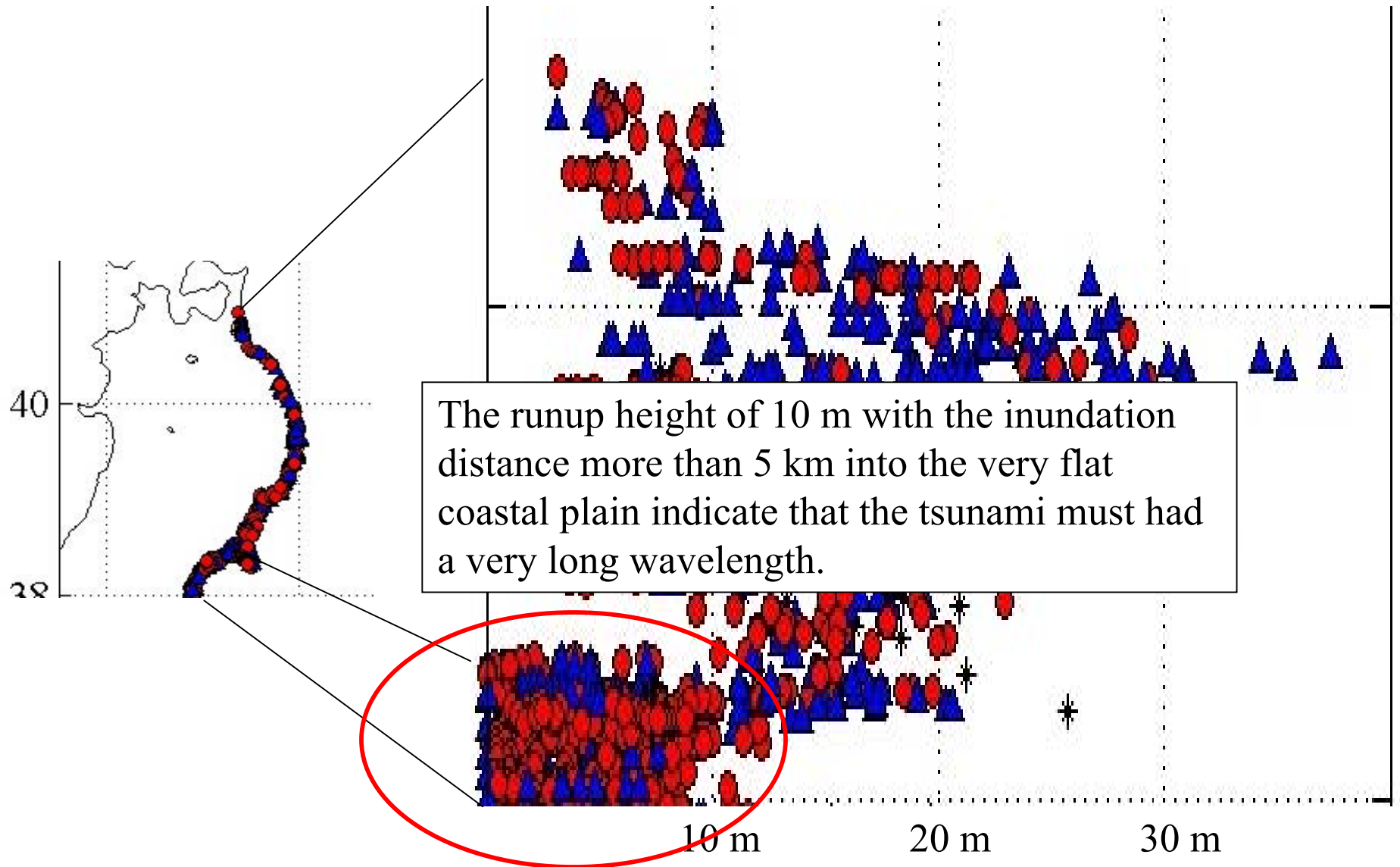




# Bathymetry

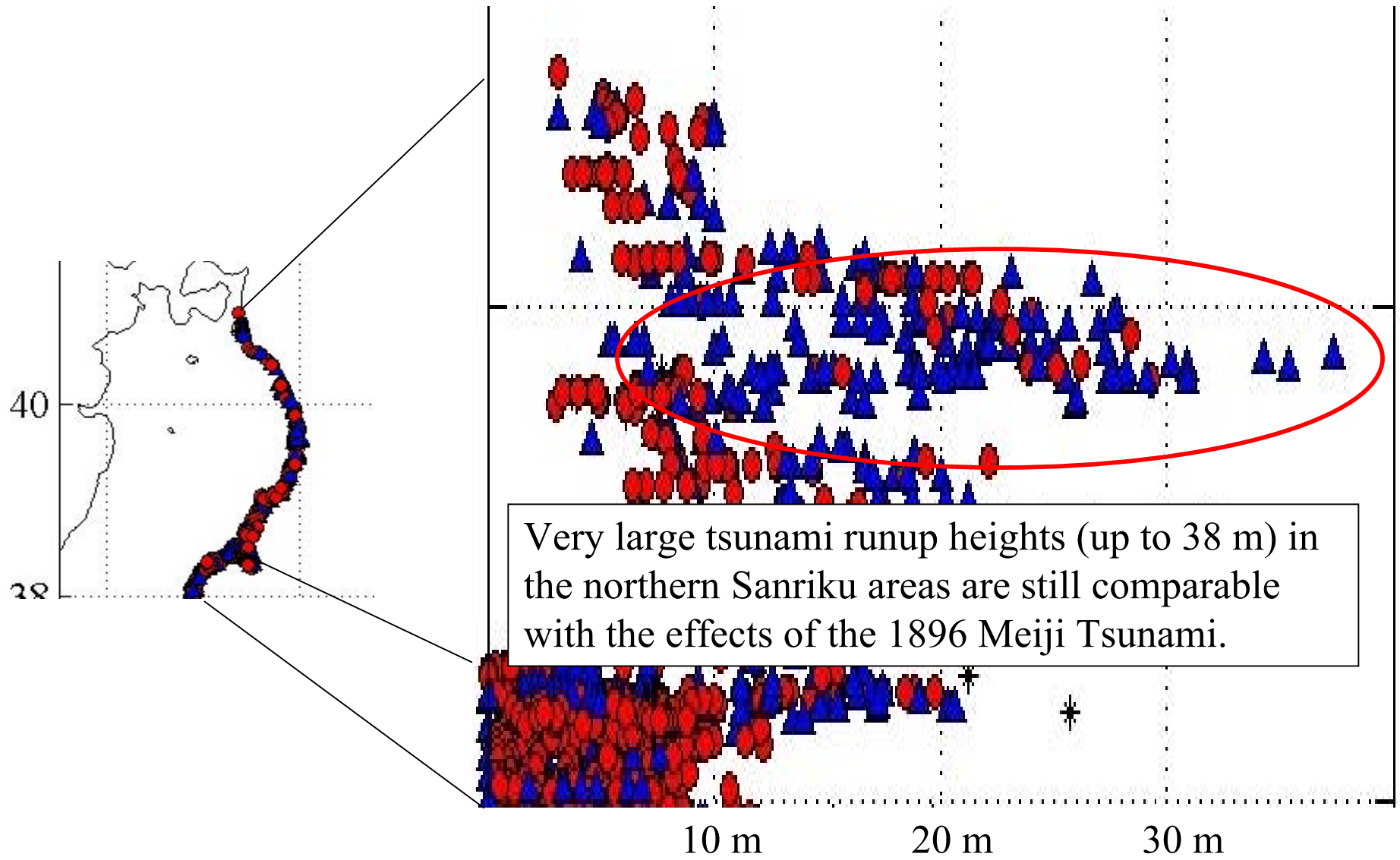


# Tsunami Runup Heights and Inundation Heights

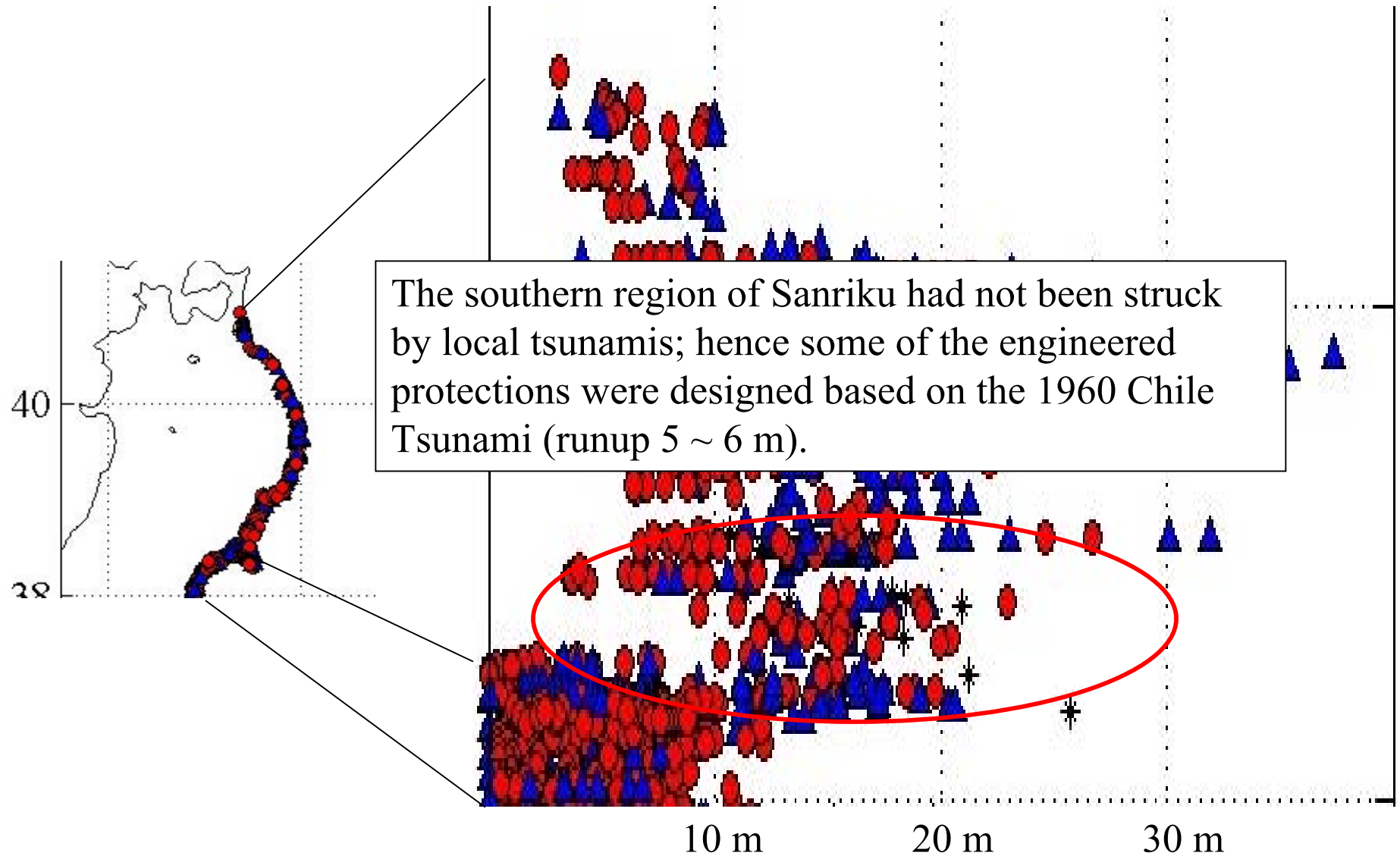




# Tsunami Runup Heights and Inundation Heights

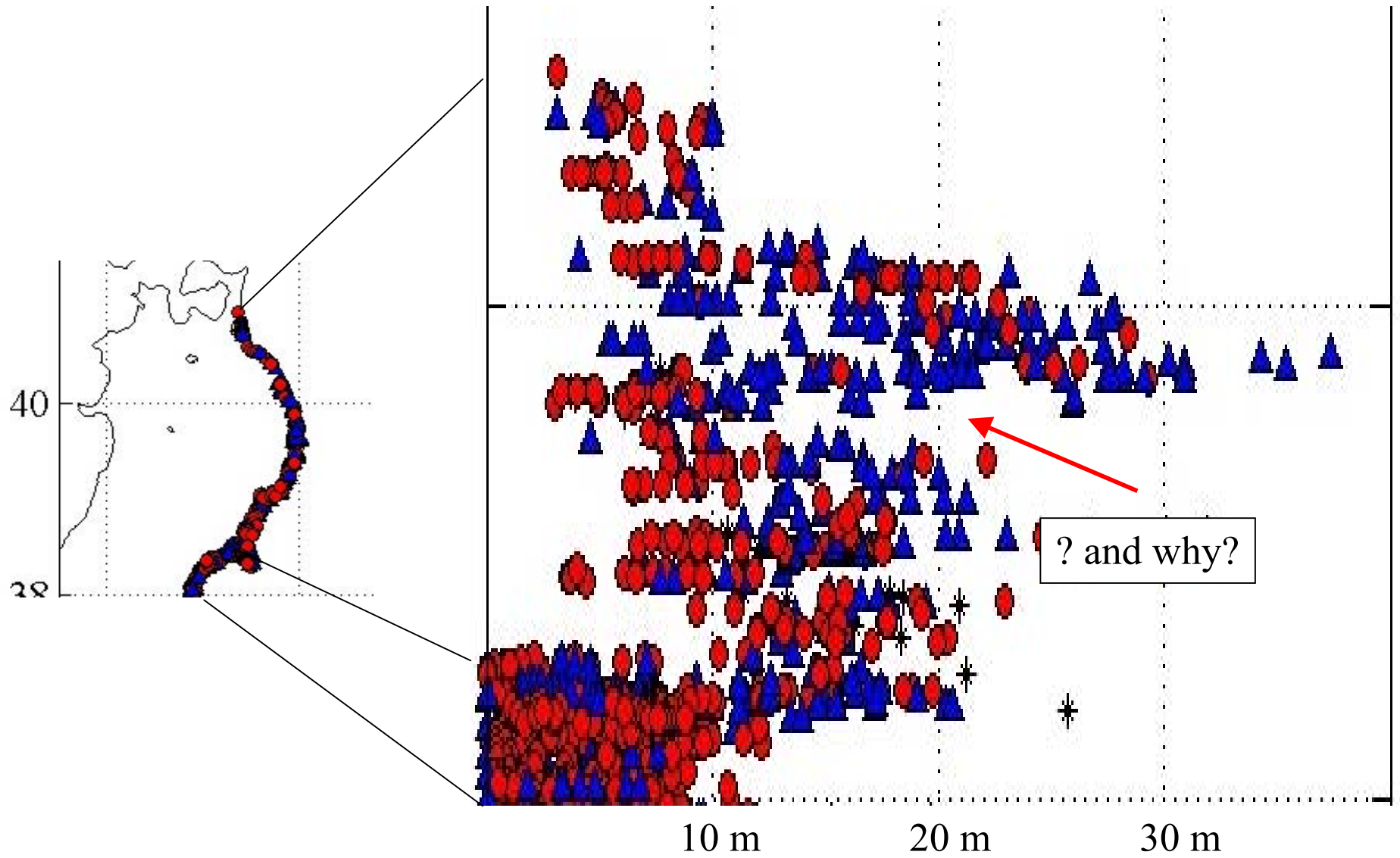


# Tsunami Runup Heights and Inundation Heights

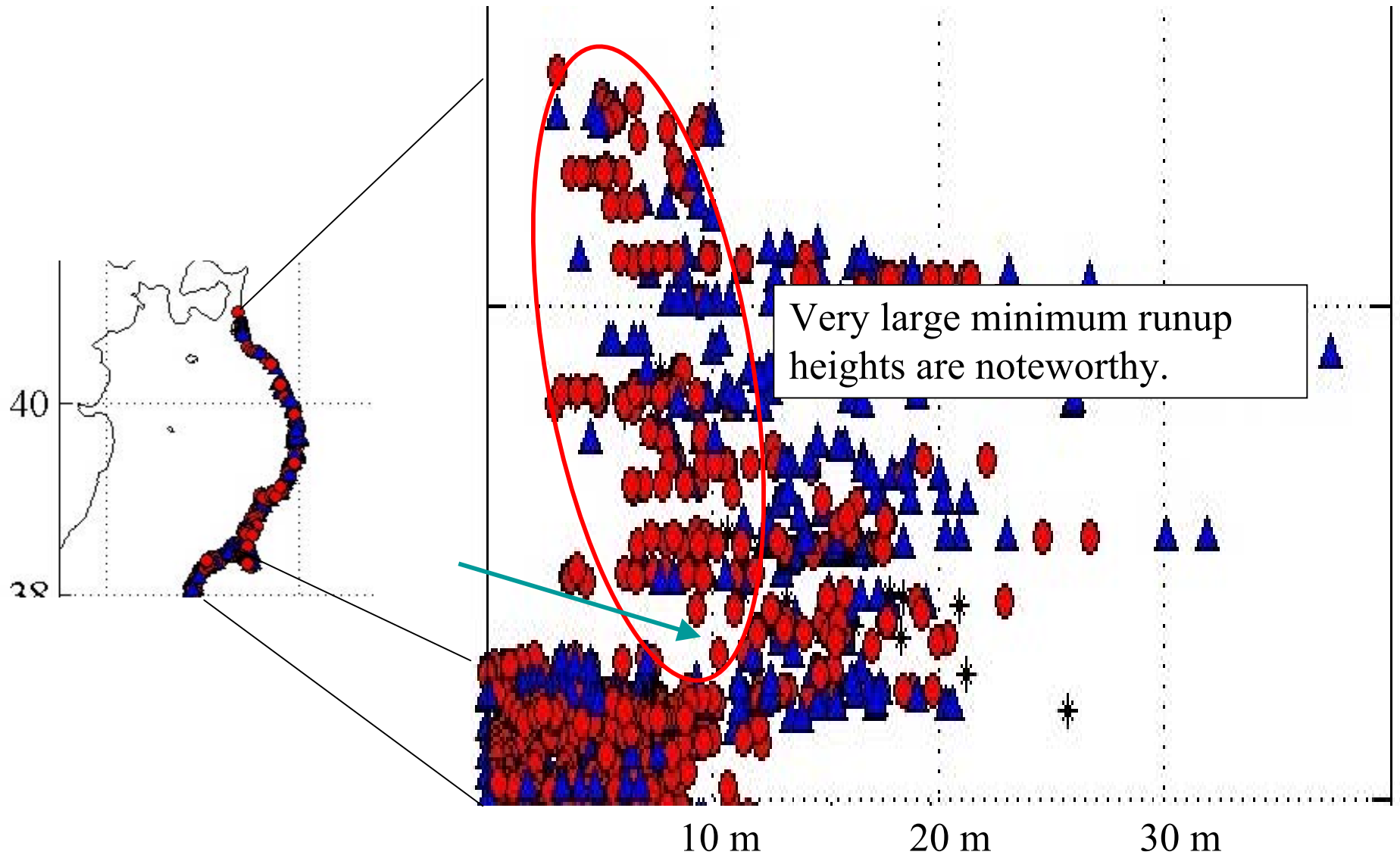




# Tsunami Runup Heights and Inundation Heights



# Tsunami Runup Heights and Inundation Heights





# Summary

Lots of things to learn from this natural disaster.  
especially for the future Cascadia event.

# Tsunami Heights and the Heights of Seawalls

